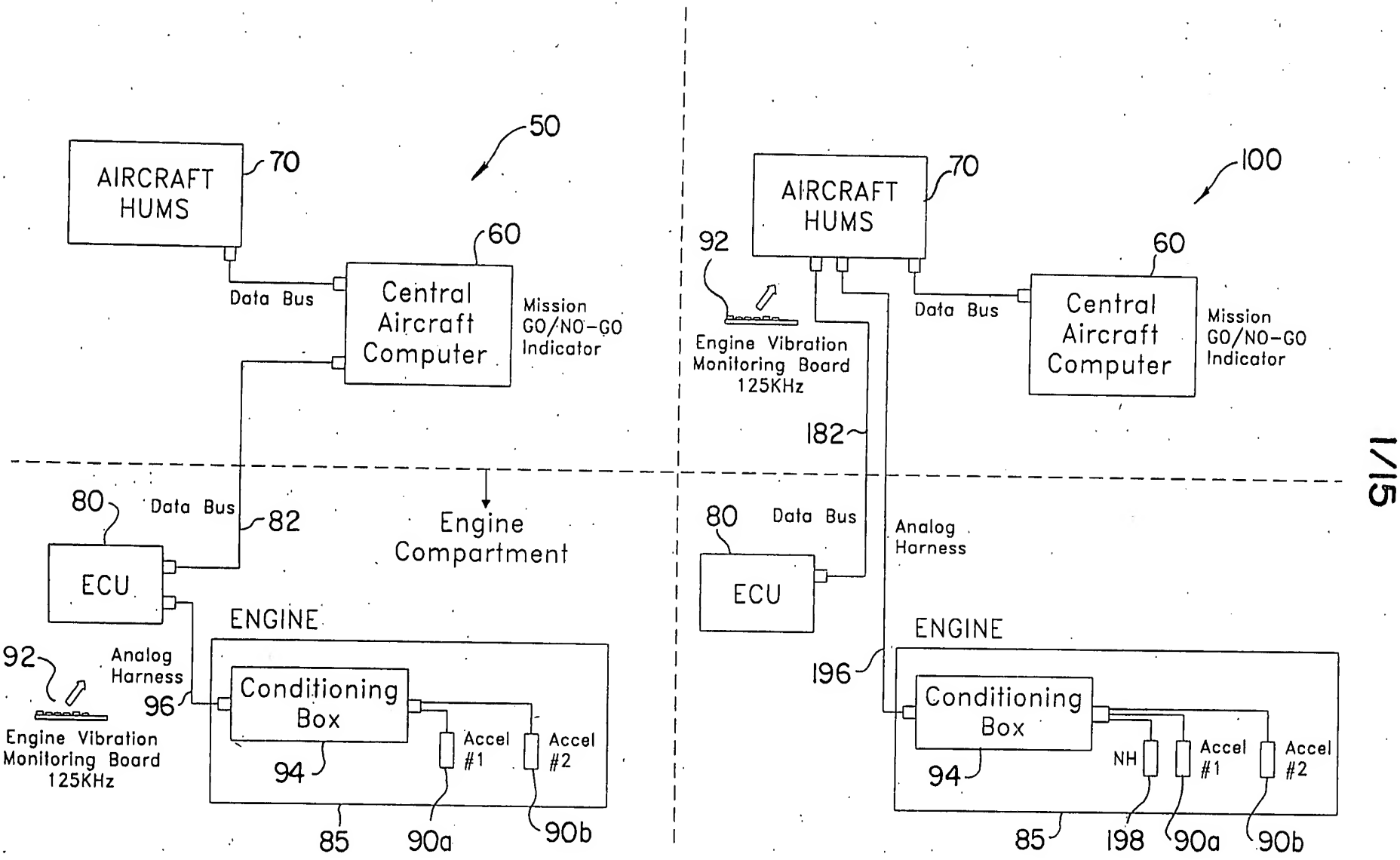

50
AIRCRAFT HUMS
70
60
Data Bus
Central Aircraft Computer
Mission GO/NO-GO Indicator
80
Data Bus
82
ECU
Engine Compartment
ENGINE
92
Analog Harness
96
Conditioning Box
Accel #1
Accel #2
Engine Vibration Monitoring Board 125KHz
94
85
90a
90b
100
AIRCRAFT HUMS
70
92
60
Data Bus
Central Aircraft Computer
Mission GO/NO-GO Indicator
Engine Vibration Monitoring Board 125KHz
182
80
Data Bus
Analog Harness
ECU
ENGINE
196
Conditioning Box
NH
Accel #1
Accel #2
94
85
198
90a
90b

FIG. 1

1/15

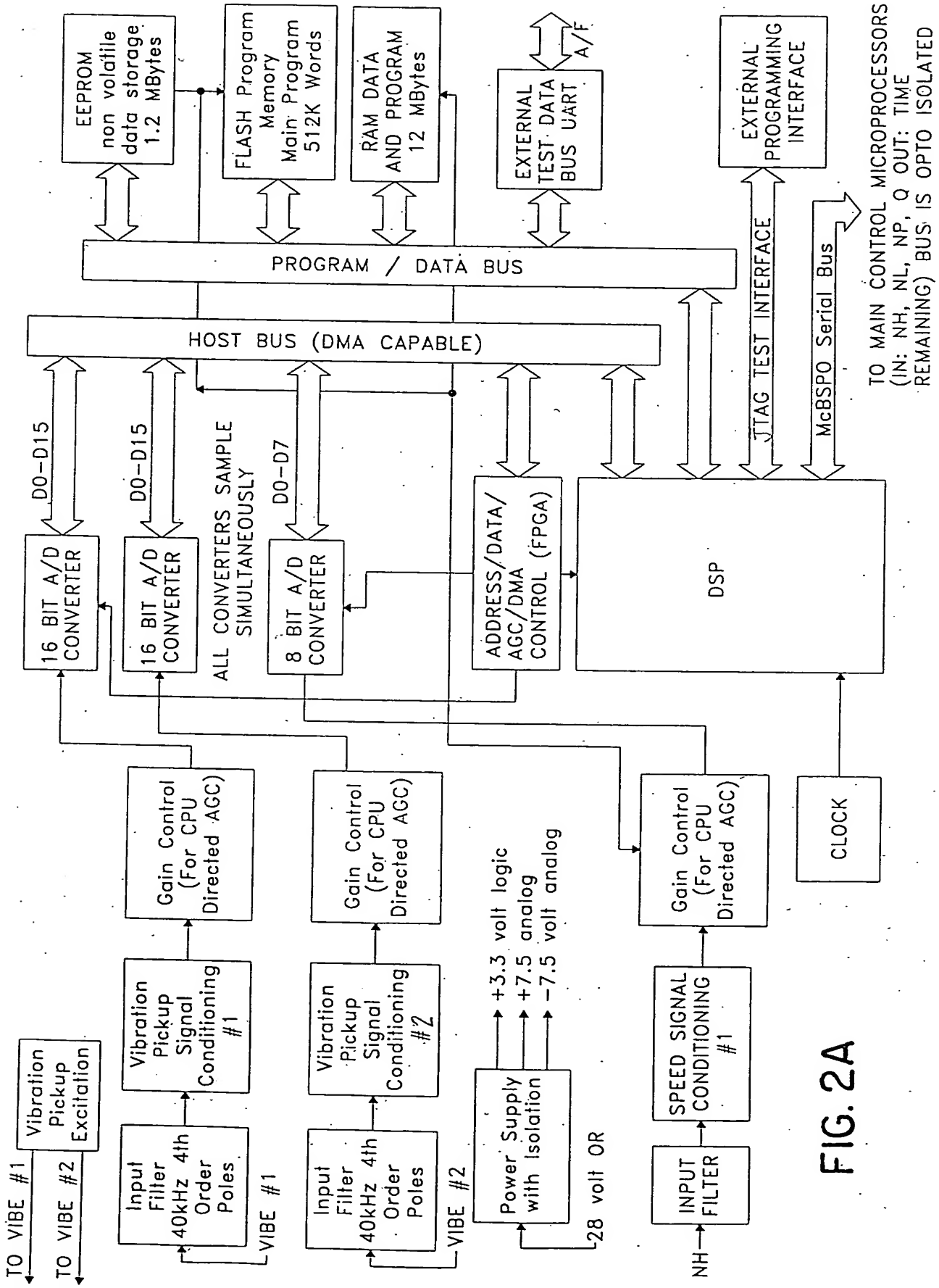

EEPROM non volatile data storage 1.2 MBytes
FLASH Program Memory Main Program 512K Words
RAM DATA AND PROGRAM 12 MBytes
EXTERNAL TEST DATA BUS UART
A/F
EXTERNAL PROGRAMMING INTERFACE
PROGRAM / DATA BUS
HOST BUS (DMA CAPABLE)
JTAG TEST INTERFACE
McBSPO Serial Bus
TO MAIN CONTROL MICROPROCESSORS (IN: NH, NL, NP, Q OUT: TIME REMAINING) BUS IS OPTO ISOLATED
D0-D15
D0-D15
D0-D7
ALL CONVERTERS SAMPLE SIMULTANEOUSLY
16 BIT A/D CONVERTER
16 BIT A/D CONVERTER
8 BIT A/D CONVERTER
ADDRESS/DATA/ AGC/DMA CONTROL (FPGA)
DSP
Gain Control (For CPU Directed AGC)
Gain Control (For CPU Directed AGC)
Gain Control (For CPU Directed AGC)
CLOCK
Vibration Pickup Signal Conditioning #1
Vibration Pickup Signal Conditioning #2
+3.3 volt logic
+7.5 analog
-7.5 volt analog
SPEED SIGNAL CONDITIONING #1
Vibration Pickup Excitation
Input Filter 40kHz 4th Order Poles
Input Filter 40kHz 4th Order Poles
Power Supply with Isolation
INPUT FILTER
TO VIBE #1
TO VIBE #2
VIBE #1
VIBE #2
28 volt OR
NH

FIG. 2A

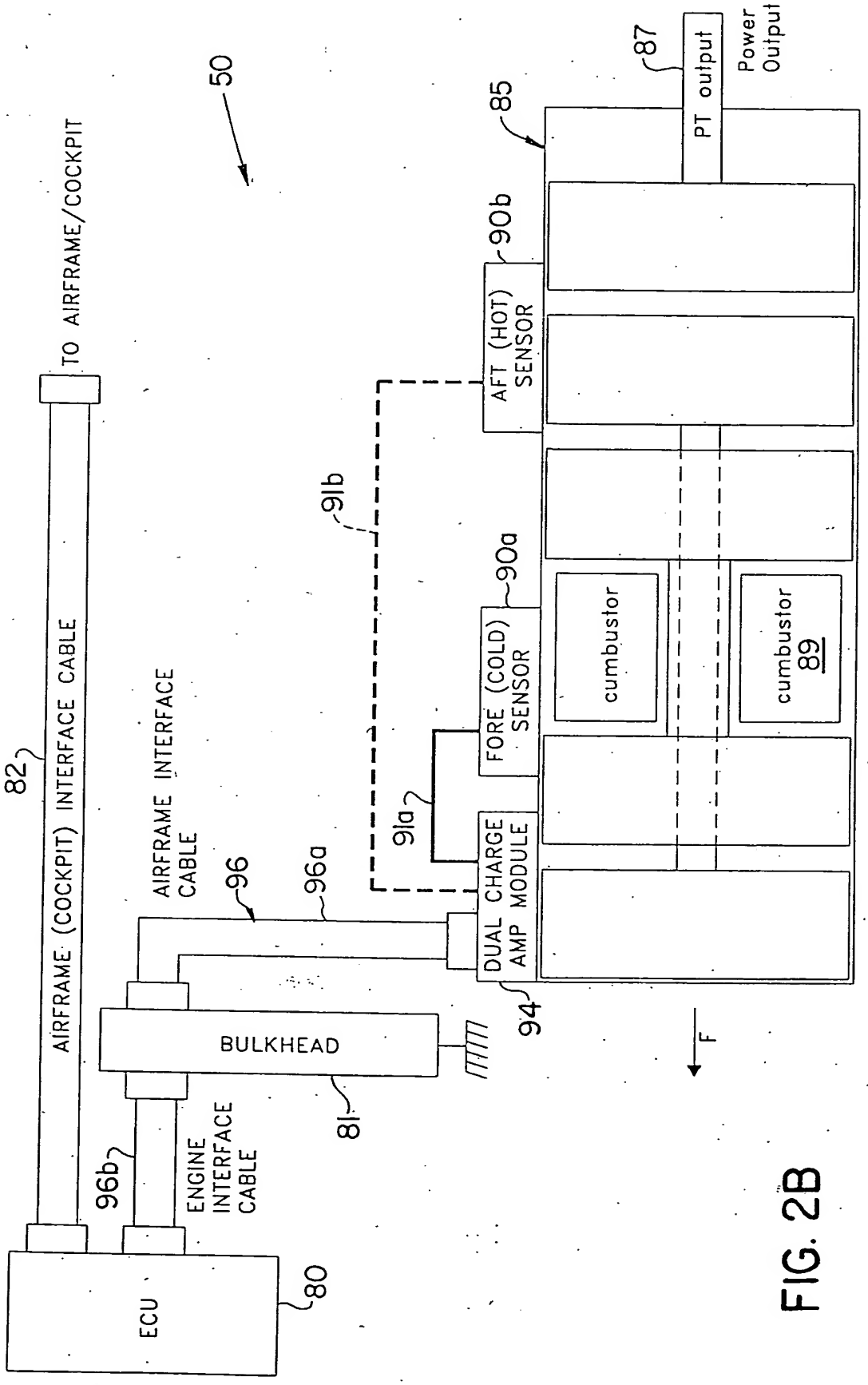

50
TO AIRFRAME/COCKPIT
AIRFRAME (COCKPIT) INTERFACE CABLE
82
AIRFRAME INTERFACE CABLE
96
96a
96b
ENGINE INTERFACE CABLE
BULKHEAD
81
ECU
80
91a
91b
DUAL CHARGE AMP MODULE
94
FORE (COLD) SENSOR
90a
AFT (HOT) SENSOR
90b
cumbustor
cumbustor 89
85
PT output
87
Power Output
F

FIG. 2B

FIG. 3A

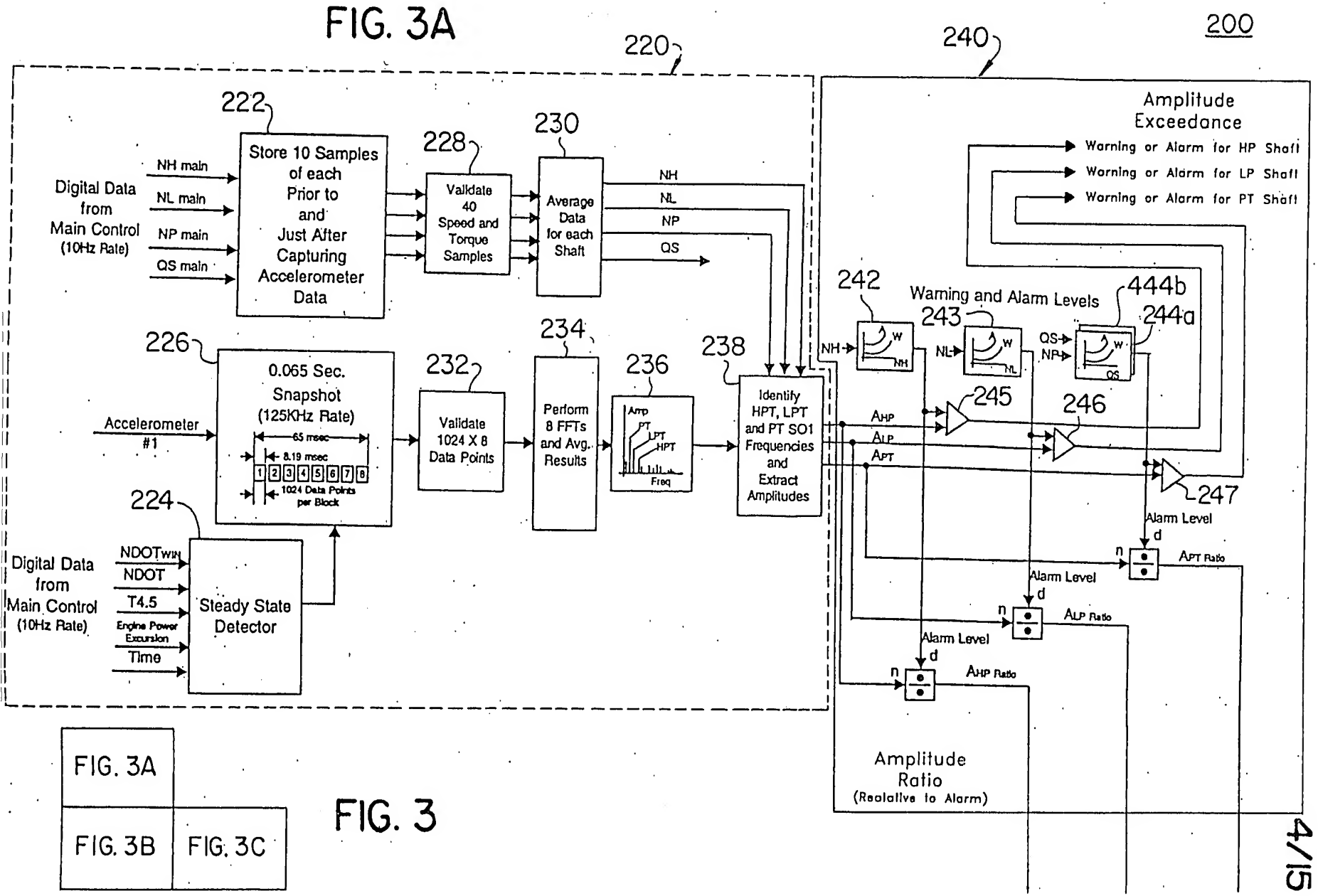



FIG. 3

| | |
|---|---|
| FIG. 3A | |
| FIG. 3B | FIG. 3C |

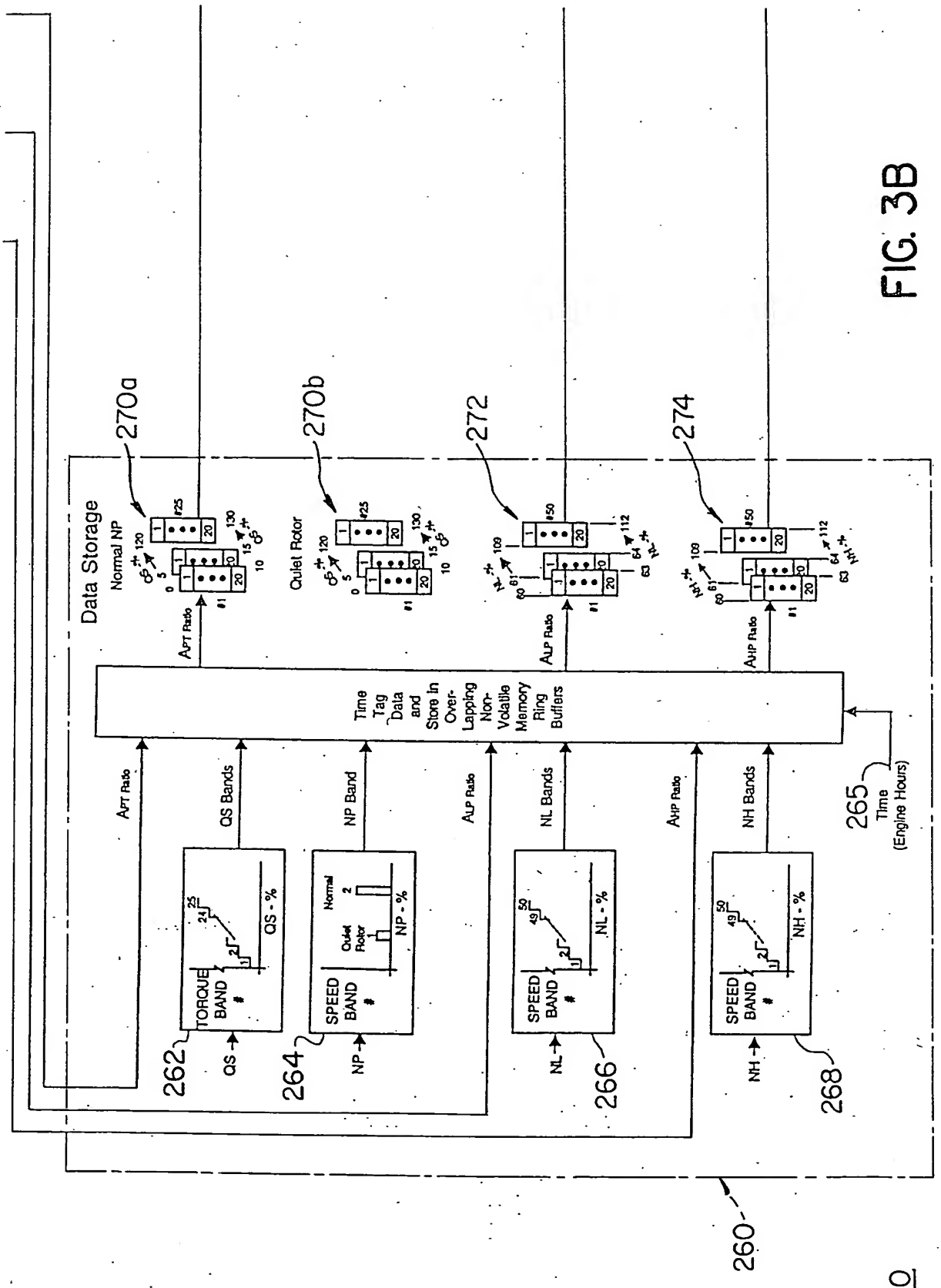

Data Storage
Normal NP
Quiet Rotor
270a
270b
272
274
APT Ratio
ALP Ratio
AHP Ratio
Time Tag Data and Store in Over-Lapping Non-Volatile Memory Ring Buffers
QS Bands
NP Band
NL Bands
NH Bands
265
Time
(Engine Hours)
TORQUE BAND
SPEED BAND
QS - %
NP - %
NL - %
NH - %
QS
NP
NL
NH
262
264
266
268
260
200

FIG. 3B

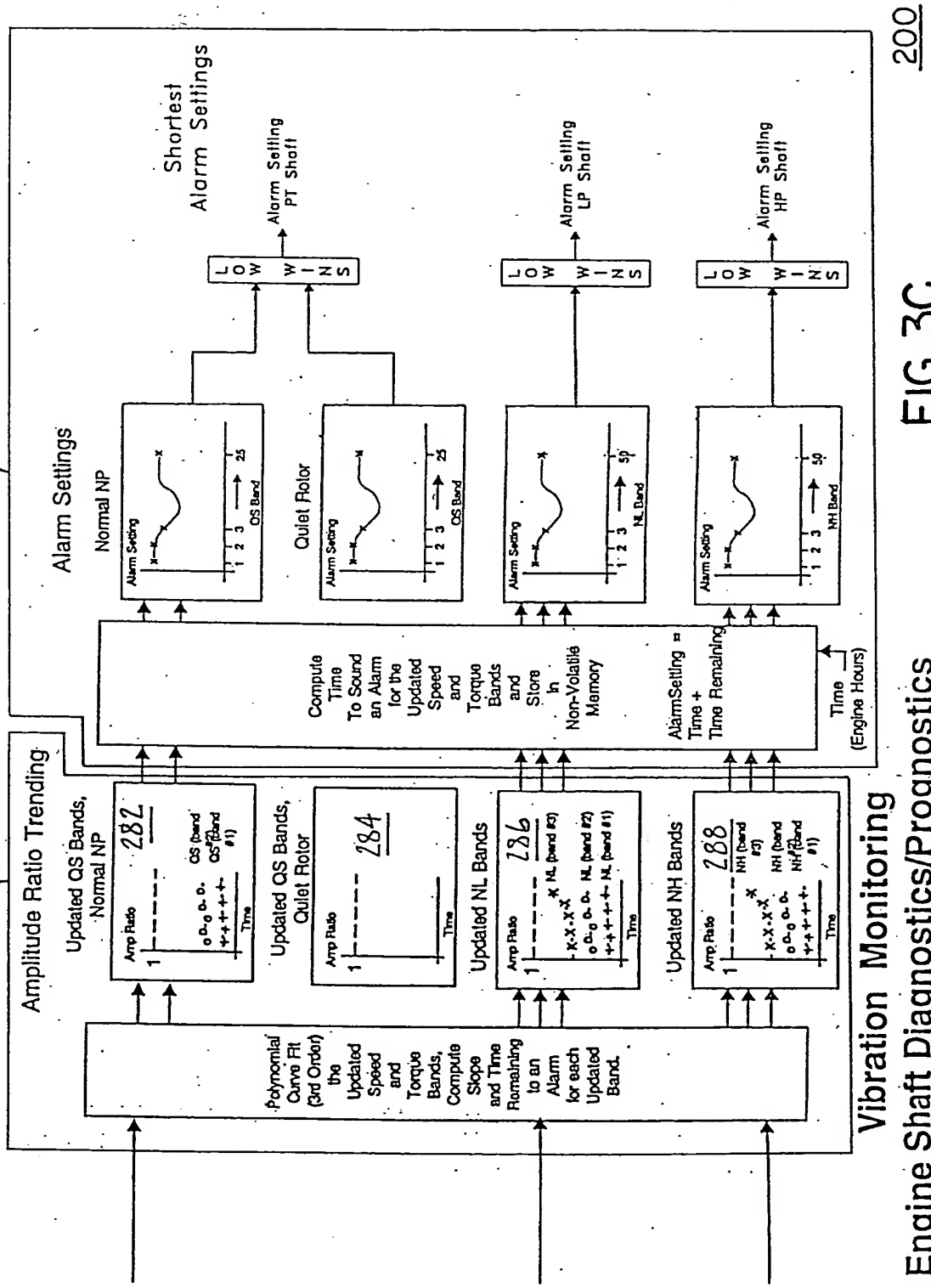
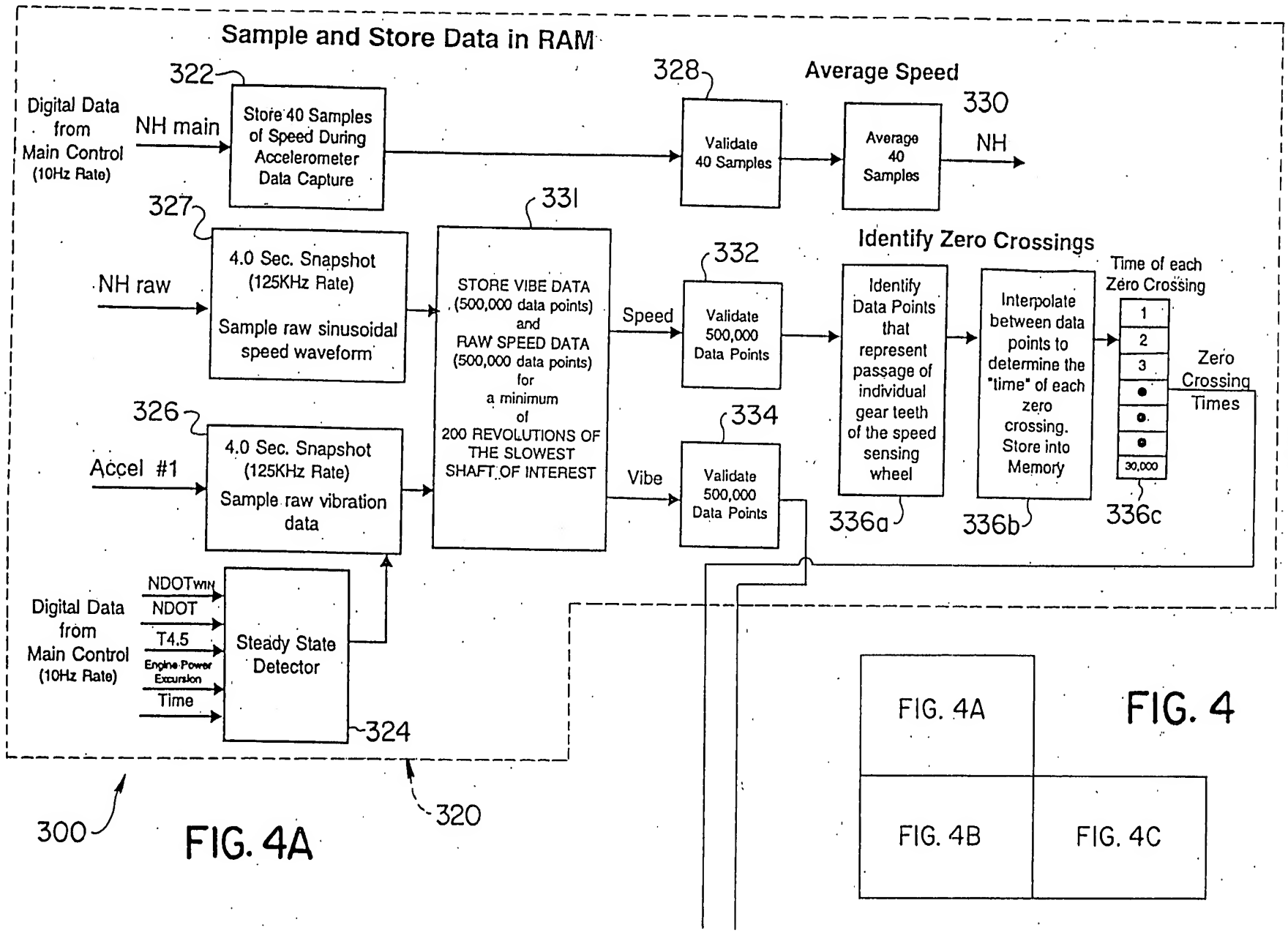
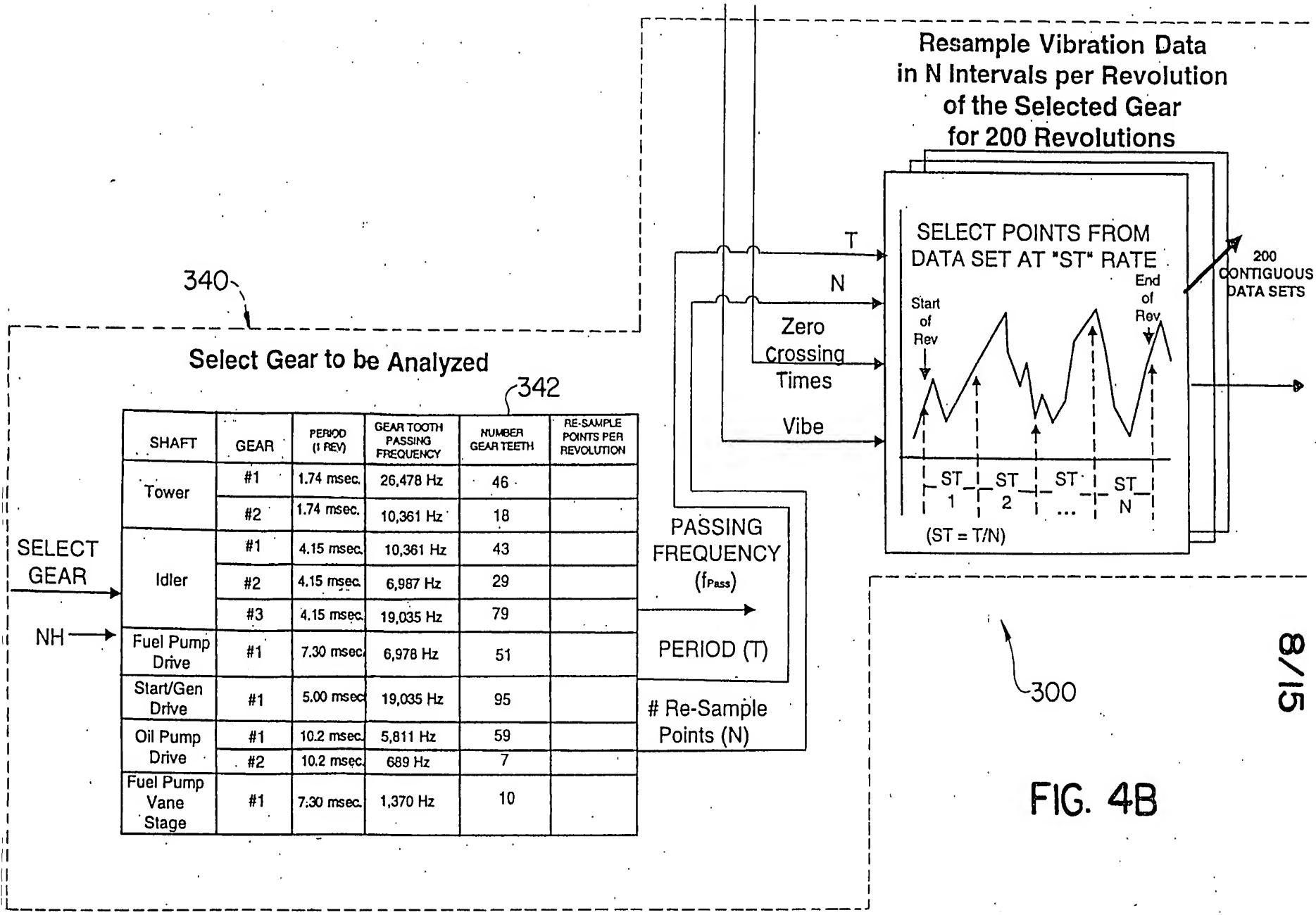

Engine Shaft Diagnostics/Prognostics
Vibration Monitoring
200
280
Amplitude Ratio Trending
Polynomial Curve Fit (3rd Order) the Updated Speed and Torque Bands, Compute Slope and Time Remaining to an Alarm for each Updated Band.
Updated QS Bands, Normal NP
282
Updated QS Bands, Quiet Rotor
284
Updated NL Bands
286
Updated NH Bands
288
290
Alarm Settings
Normal NP
Quiet Rotor
Compute Time To Sound an Alarm for the Updated Speed and Torque Bands and Store in Non-Volatile Memory
AlarmSetting = Time + Time Remaining
Time (Engine Hours)
Shortest Alarm Settings
Alarm Setting PT Shaft
Alarm Setting LP Shaft
Alarm Setting HP Shaft
LOW WINS

FIG. 3C


Sample and Store Data in RAM
322
Digital Data from Main Control (10Hz Rate)
NH main
Store 40 Samples of Speed During Accelerometer Data Capture
328
Validate 40 Samples
Average Speed
Average 40 Samples
330
NH
327
NH raw
4.0 Sec. Snapshot (125KHz Rate)
Sample raw sinusoidal speed waveform
331
STORE VIBE DATA (500,000 data points) and RAW SPEED DATA (500,000 data points) for a minimum of 200 REVOLUTIONS OF THE SLOWEST SHAFT OF INTEREST
Speed
332
Validate 500,000 Data Points
Identify Zero Crossings
Identify Data Points that represent passage of individual gear teeth of the speed sensing wheel
Interpolate between data points to determine the "time" of each zero crossing. Store into Memory
Time of each Zero Crossing
1
2
3
30,000
Zero Crossing Times
336a
336b
336c
326
Accel #1
4.0 Sec. Snapshot (125KHz Rate)
Sample raw vibration data
Vibe
334
Validate 500,000 Data Points
Digital Data from Main Control (10Hz Rate)
NDOTWIN
NDOT
T4.5
Engine Power Excursion
Time
Steady State Detector
324
320
300
FIG. 4A
7/15
FIG. 4A
FIG. 4B
FIG. 4C
FIG. 4




| SHAFT | GEAR | PERIOD (1 REV) | GEAR TOOTH PASSING FREQUENCY | NUMBER GEAR TEETH | RE-SAMPLE POINTS PER REVOLUTION |
|---|---|---|---|---|---|
| Tower | #1 | 1.74 msec. | 26,478 Hz | 46 | |
| | #2 | 1.74 msec. | 10,361 Hz | 18 | |
| Idler | #1 | 4.15 msec. | 10,361 Hz | 43 | |
| | #2 | 4.15 msec. | 6,987 Hz | 29 | |
| | #3 | 4.15 msec. | 19,035 Hz | 79 | |
| Fuel Pump Drive | #1 | 7.30 msec. | 6,978 Hz | 51 | |
| Start/Gen Drive | #1 | 5.00 msec | 19,035 Hz | 95 | |
| Oil Pump Drive | #1 | 10.2 msec. | 5,811 Hz | 59 | |
| | #2 | 10.2 msec. | 689 Hz | 7 | |
| Fuel Pump Vane Stage | #1 | 7.30 msec. | 1,370 Hz | 10 | |

FIG. 4B

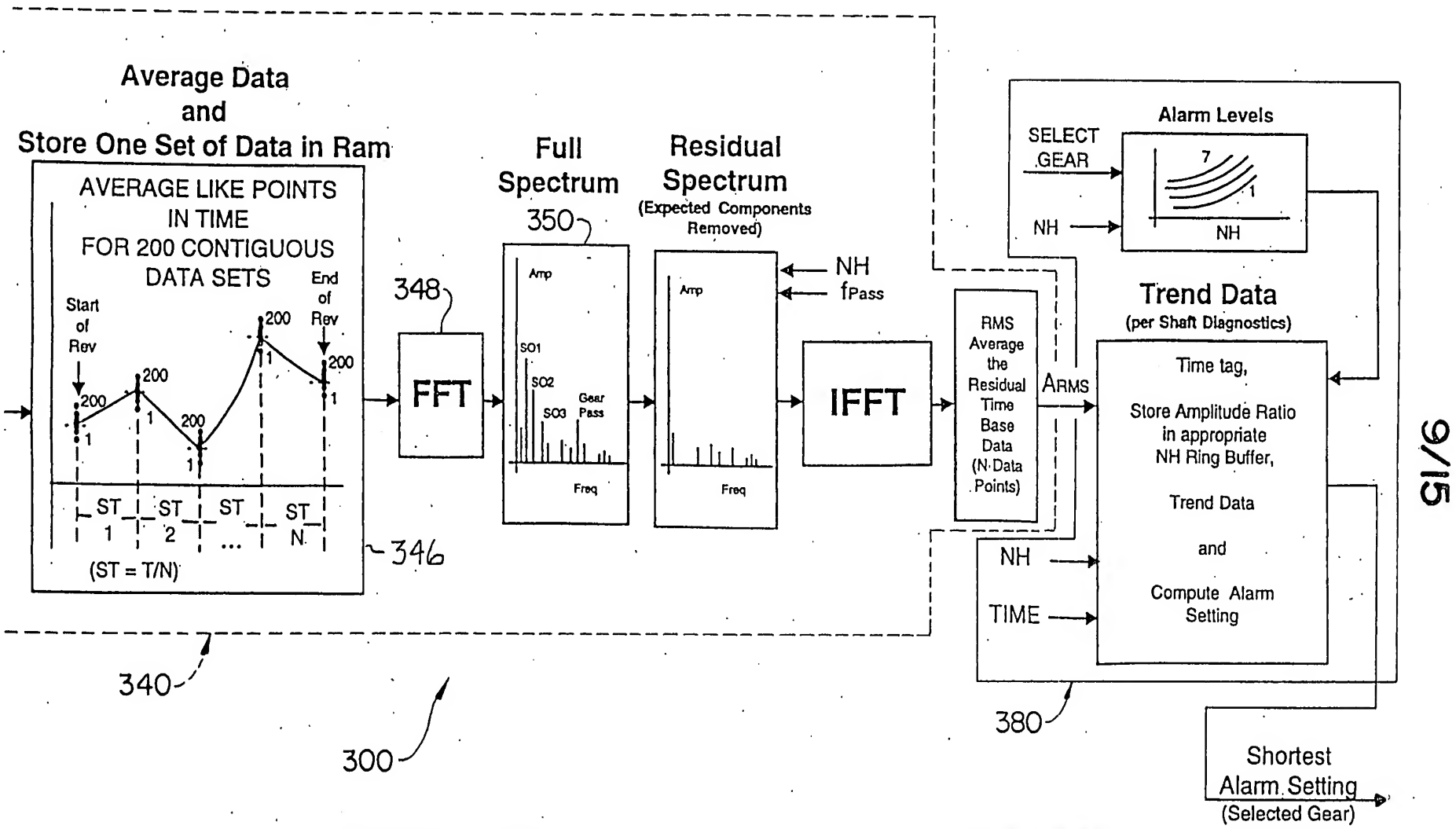
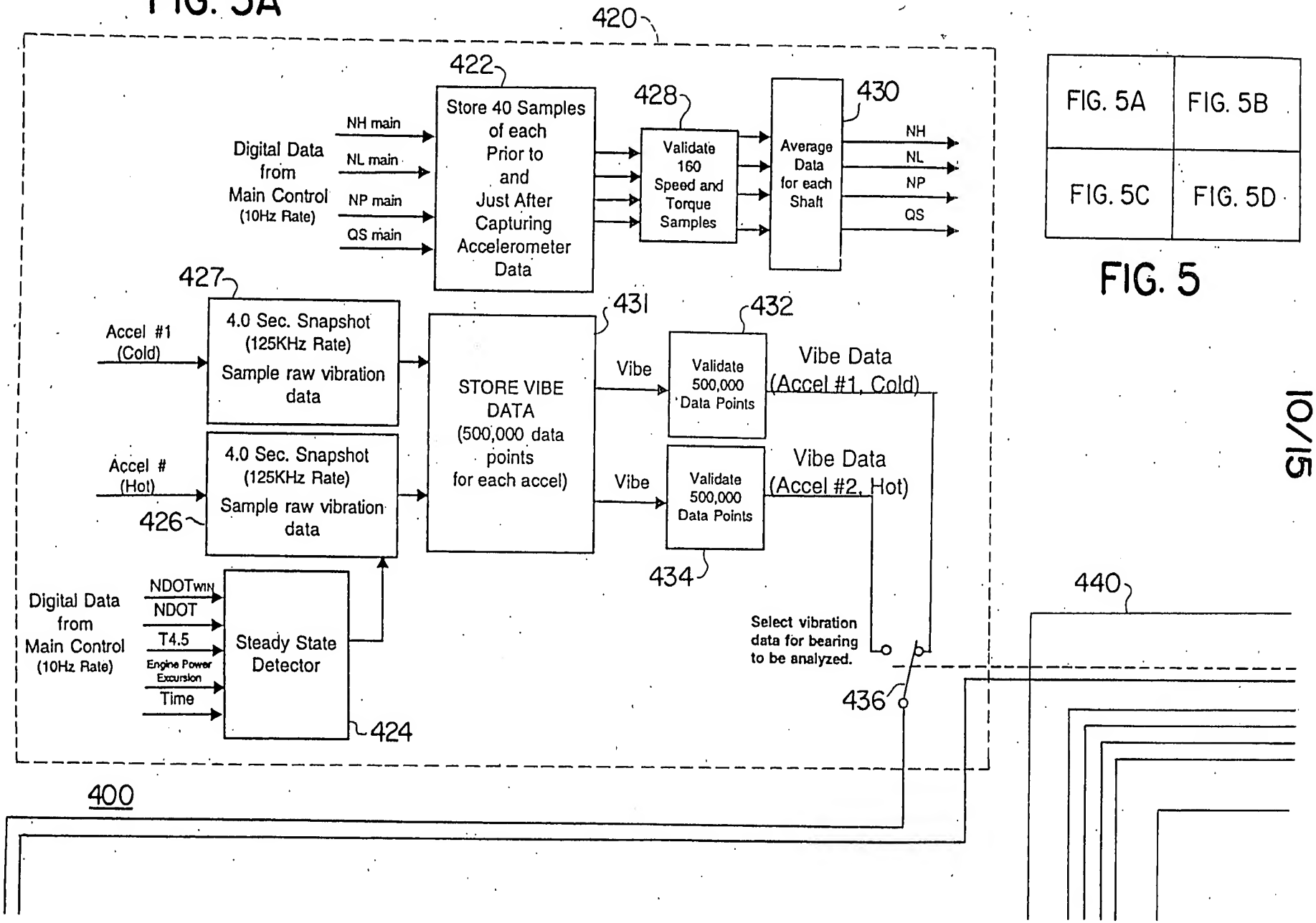



FIG. 4C

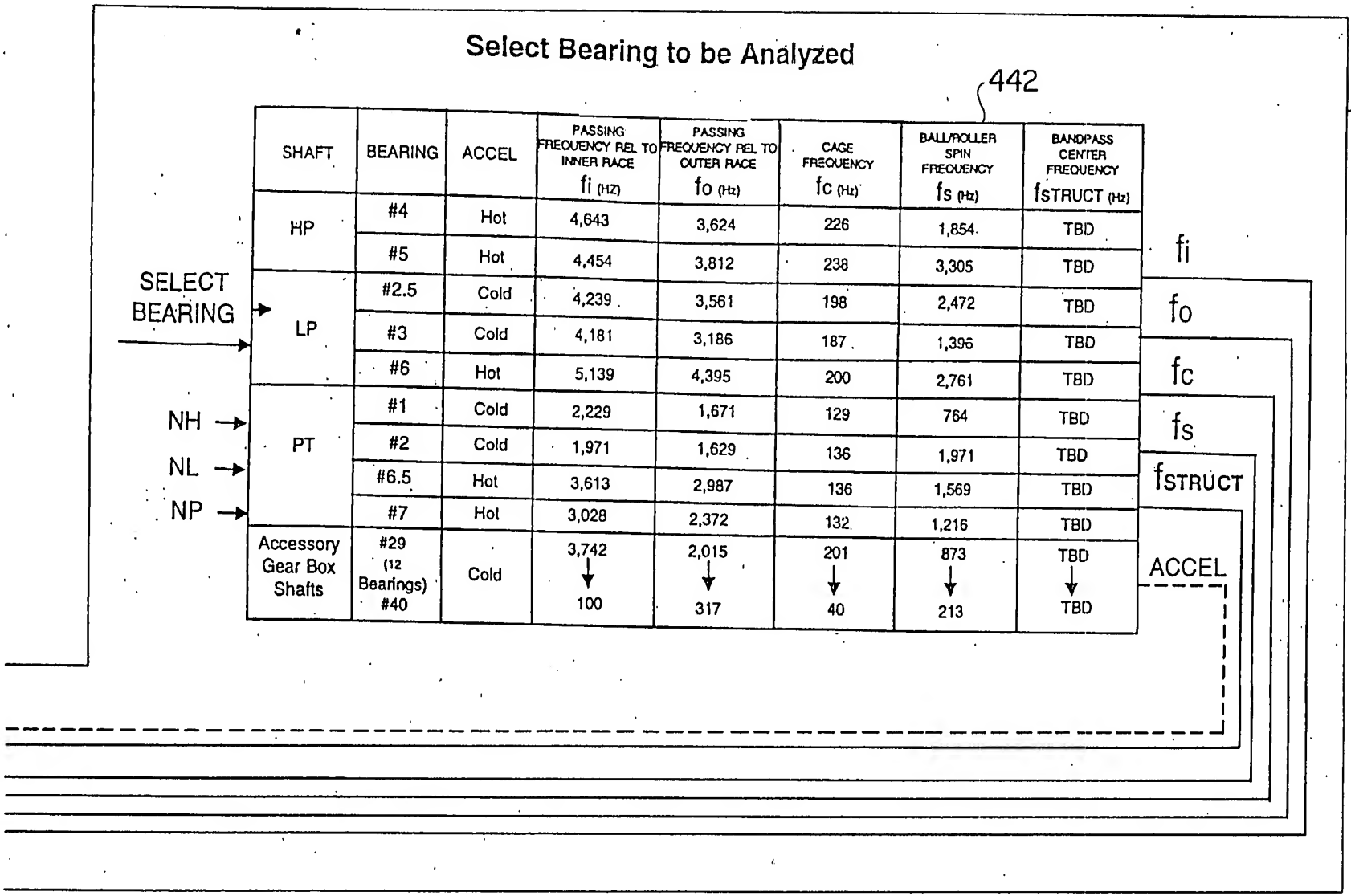
Vibration Monitoring
Engine Gear Diagnostics / Prognostics

FIG. 5A




| | |
|---|---|
| FIG. 5A | FIG. 5B |
| FIG. 5C | FIG. 5D |

FIG. 5

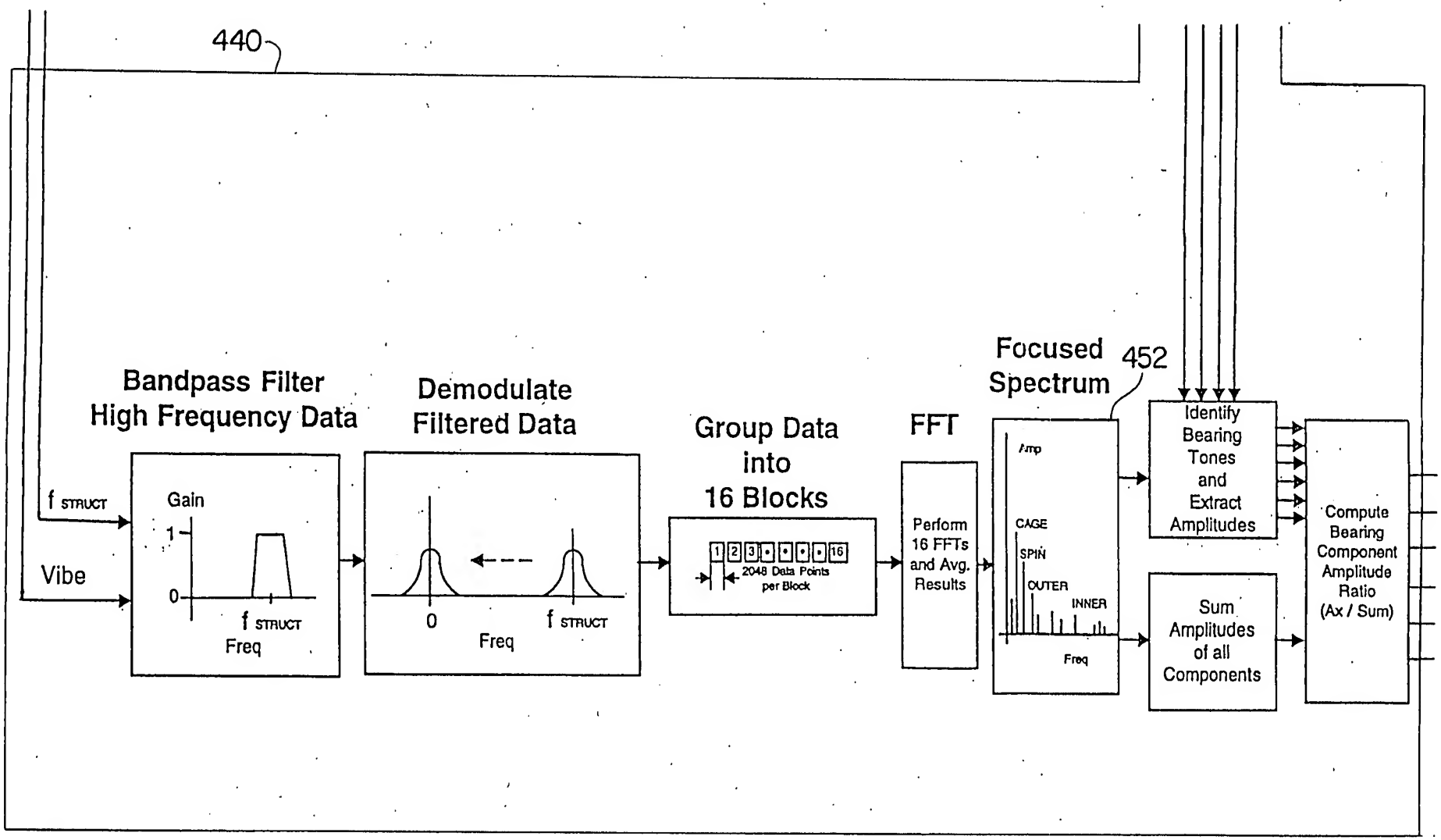



| SHAFT | BEARING | ACCEL | PASSING FREQUENCY REL TO INNER RACE fi (HZ) | PASSING FREQUENCY REL TO OUTER RACE fo (Hz) | CAGE FREQUENCY fc (Hz) | BALL/ROLLER SPIN FREQUENCY fs (Hz) | BANDPASS CENTER FREQUENCY fSTRUCT (Hz) |
|---|---|---|---|---|---|---|---|
| HP | #4 | Hot | 4,643 | 3,624 | 226 | 1,854 | TBD |
| | #5 | Hot | 4,454 | 3,812 | 238 | 3,305 | TBD |
| LP | #2.5 | Cold | 4,239 | 3,561 | 198 | 2,472 | TBD |
| | #3 | Cold | 4,181 | 3,186 | 187 | 1,396 | TBD |
| | #6 | Hot | 5,139 | 4,395 | 200 | 2,761 | TBD |
| PT | #1 | Cold | 2,229 | 1,671 | 129 | 764 | TBD |
| | #2 | Cold | 1,971 | 1,629 | 136 | 1,971 | TBD |
| | #6.5 | Hot | 3,613 | 2,987 | 136 | 1,569 | TBD |
| | #7 | Hot | 3,028 | 2,372 | 132 | 1,216 | TBD |
| Accessory Gear Box Shafts | #29 (12 Bearings) #40 | Cold | 3,742 ↓ 100 | 2,015 ↓ 317 | 201 ↓ 40 | 873 ↓ 213 | TBD ↓ TBD |



400

FIG. 5B




400

Vibration Monitoring
Engine Bearing Diagnostics / Prognostics

FIG. 5C

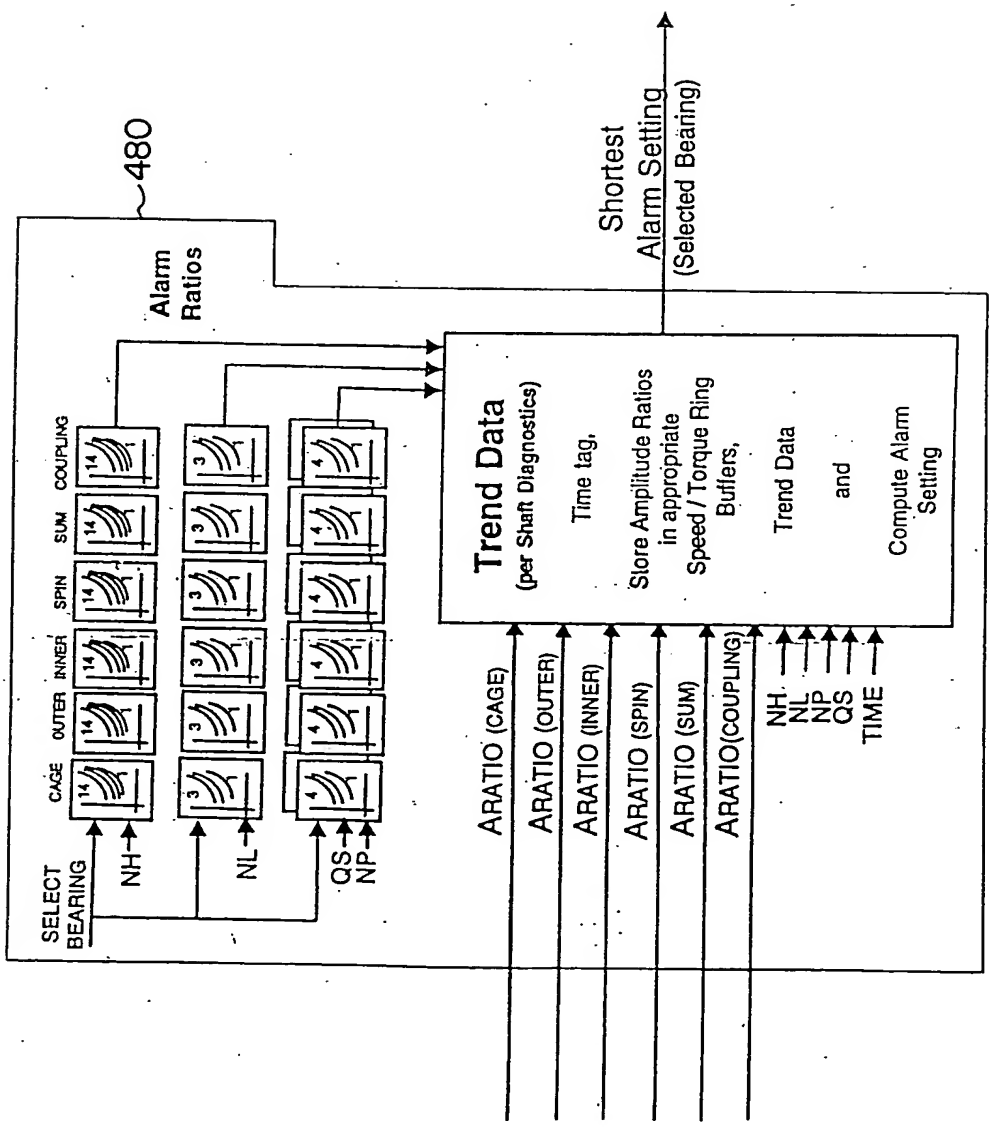
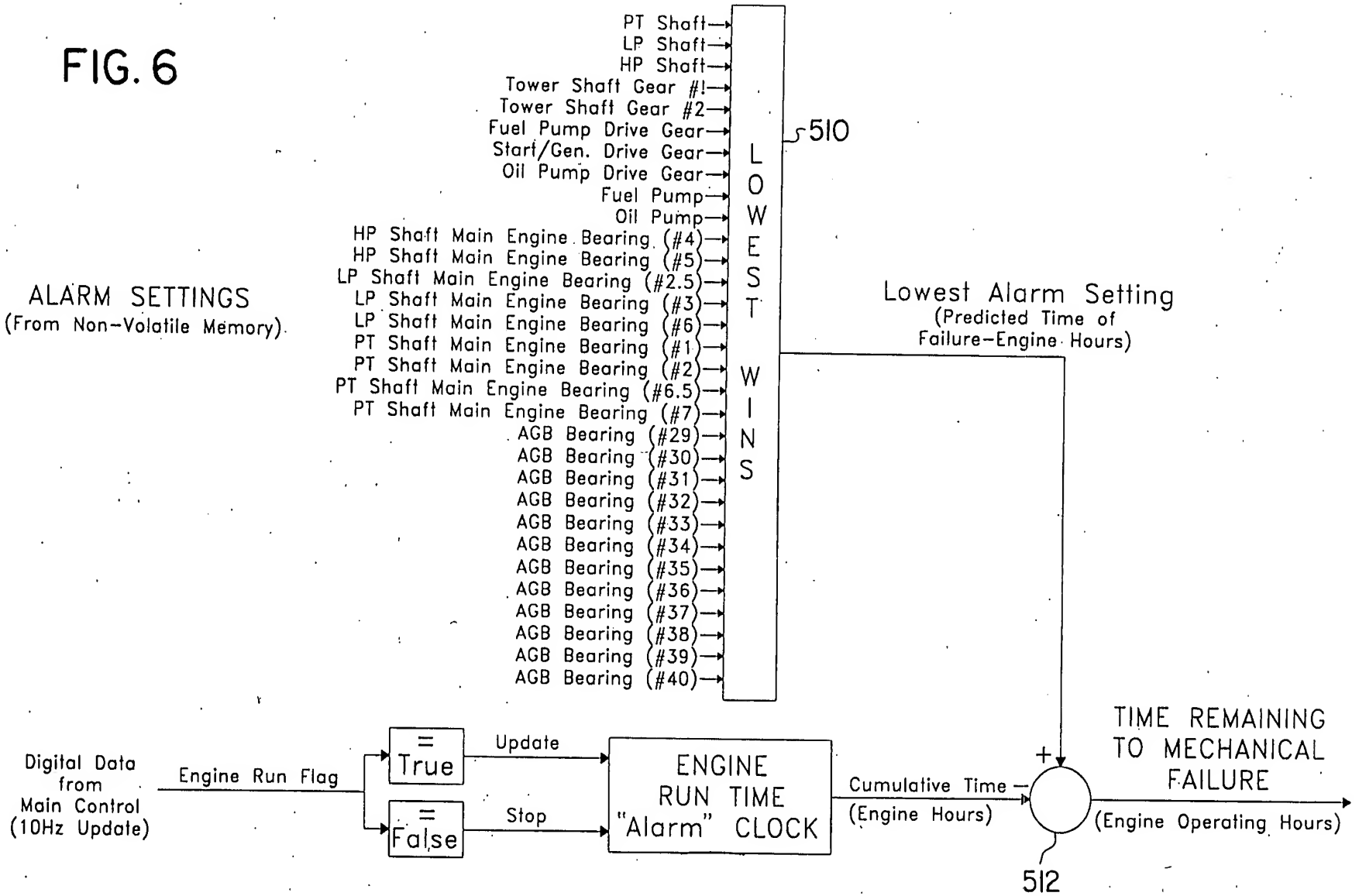

480
Alarm Ratios
SELECT BEARING
CAGE
OUTER
INNER
SPIN
SUM
COUPLING
NH
NL
QS
NP
Trend Data
(per Shaft Diagnostics)
Time tag,
Store Amplitude Ratios in appropriate Speed / Torque Ring Buffers,
Trend Data
and
Compute Alarm Setting
Shortest Alarm Setting
(Selected Bearing)
ARATIO (CAGE)
ARATIO (OUTER)
ARATIO (INNER)
ARATIO (SPIN)
ARATIO (SUM)
ARATIO(COUPLING)
NH
NL
NP
QS
TIME
400

FIG. 5D

FIG. 6


ALARM SETTINGS
(From Non-Volatile Memory)
PT Shaft
LP Shaft
HP Shaft
Tower Shaft Gear #1
Tower Shaft Gear #2
Fuel Pump Drive Gear
Start/Gen. Drive Gear
Oil Pump Drive Gear
Fuel Pump
Oil Pump
HP Shaft Main Engine Bearing (#4)
HP Shaft Main Engine Bearing (#5)
LP Shaft Main Engine Bearing (#2.5)
LP Shaft Main Engine Bearing (#3)
LP Shaft Main Engine Bearing (#6)
PT Shaft Main Engine Bearing (#1)
PT Shaft Main Engine Bearing (#2)
PT Shaft Main Engine Bearing (#6.5)
PT Shaft Main Engine Bearing (#7)
AGB Bearing (#29)
AGB Bearing (#30)
AGB Bearing (#31)
AGB Bearing (#32)
AGB Bearing (#33)
AGB Bearing (#34)
AGB Bearing (#35)
AGB Bearing (#36)
AGB Bearing (#37)
AGB Bearing (#38)
AGB Bearing (#39)
AGB Bearing (#40)
LOWEST WINS
510
Lowest Alarm Setting
(Predicted Time of Failure-Engine Hours)
Digital Data from Main Control (10Hz Update)
Engine Run Flag
= True
= False
Update
Stop
ENGINE RUN TIME "Alarm" CLOCK
Cumulative Time
(Engine Hours)
+
512
TIME REMAINING TO MECHANICAL FAILURE
(Engine Operating Hours)

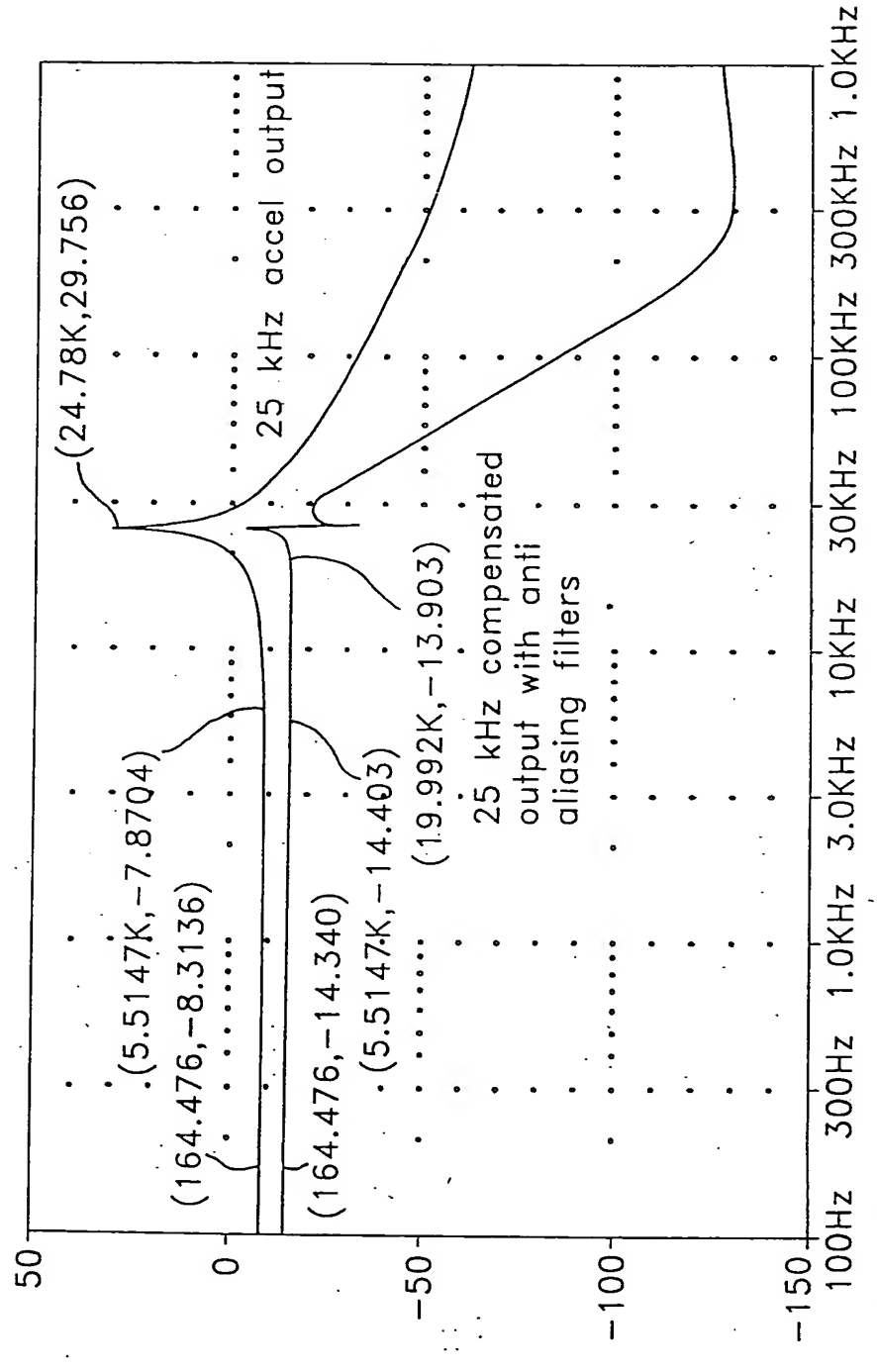

(24.78K,29.756)
25 kHz accel output
(5.5147K,-7.8704)
(164.476,-8.3136)
(164.476,-14.340)
(5.5147K,-14.403)
(19.992K,-13.903)
25 kHz compensated
output with anti
aliasing filters
50
0
-50
-100
-150
100Hz
300Hz
1.0KHz
3.0KHz
10KHz
30KHz
100KHz
300KHz
1.0KHz
FREQUENCY
VDB(vout)
VDB(vout_2FLT)

FIG. 7